UWB Channel Measurements and Modeling for DARPA NETEX

Virginia Tech

Team

Faculty

A. Attiya
R.M. Buehrer
W.A. Davis
C. Dietrich
J.H. Reed
S. Riad
A. Safaai-Jazi
D. Sweeney

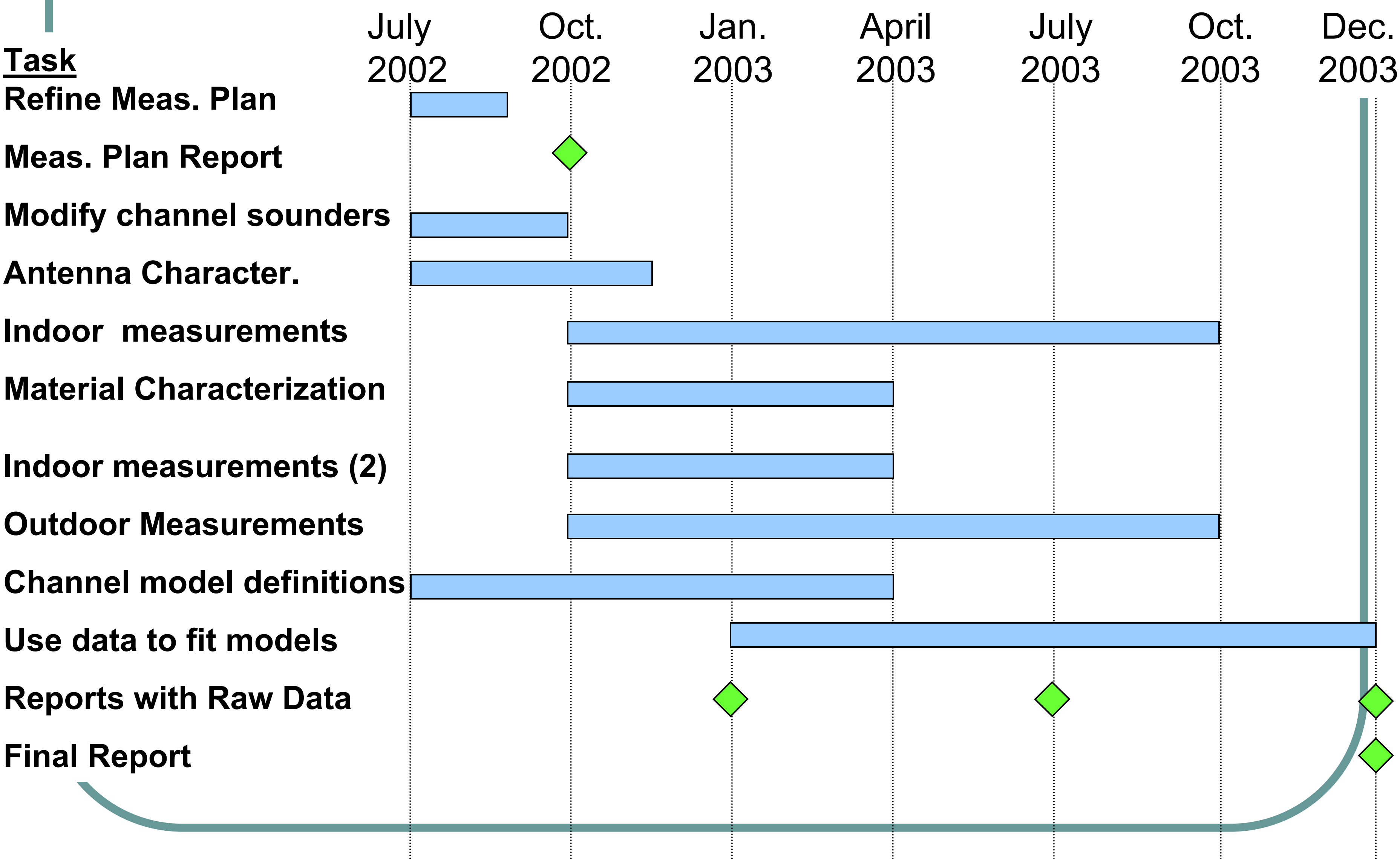
Students

C. Anderson
A. Bayram
T. Bielawa
S. Licul
N. Kumar
D. McKinstry
A. Muqaibel
J. Noronha

Project Objectives

- Develop understanding and intuition about the fundamental propagation behavior of UWB signals.
- Take large number of indoor and outdoor UWB propagation measurements (both baseband and bandpass) in order to properly characterize the behavior of UWB signals in particular environments.
- Based on these measurements, create models for link budget analysis and receiver development for a variety of deployment scenarios.

Schedule


July 2002
Oct. 2002
Jan. 2003
April 2003
July 2003
Oct. 2003
Dec. 2003
Task
Refine Meas. Plan
Meas. Plan Report
Modify channel sounders
Antenna Character.
Indoor measurements
Material Characterization
Indoor measurements (2)
Outdoor Measurements
Channel model definitions
Use data to fit models
Reports with Raw Data
Final Report

Measurement Campaign

- Indoor
  - Time domain measurements using sampling oscilloscope (100ps pulses)
  - Frequency domain measurements using VNA
    - 1-12GHz
- Outdoor
  - Time domain
  - Various frequency bands/bandwidths
  - "Low altitude" – sensor network applications
- Indoor-to-outdoor
  - Building penetration losses

Modeling

- Goal is to develop two sets of channel models for each environment
  - Path loss model
    - Necessary for link budget calculations
  - Small scale channel model
    - Number, distribution of multiple paths
    - Pulse distortion
    - Delay spread
    - Arrival rates/clustering
    - Necessary for transmitter/receiver design

Initial Model – FIR filter

- In time domain, received signal is the convolution of channel impulse response and transmitted signal.

$$r(t) = h(t) * p_{tx}(t)$$

  where $p_{tx}(t)$ is the pulse launched by the antenna (assumed to be LOS pulse)

- If reflections/diffractions, etc. are modeled as only causing an amplitude change and possibly a sign reversal, channel is discrete tapped delay line

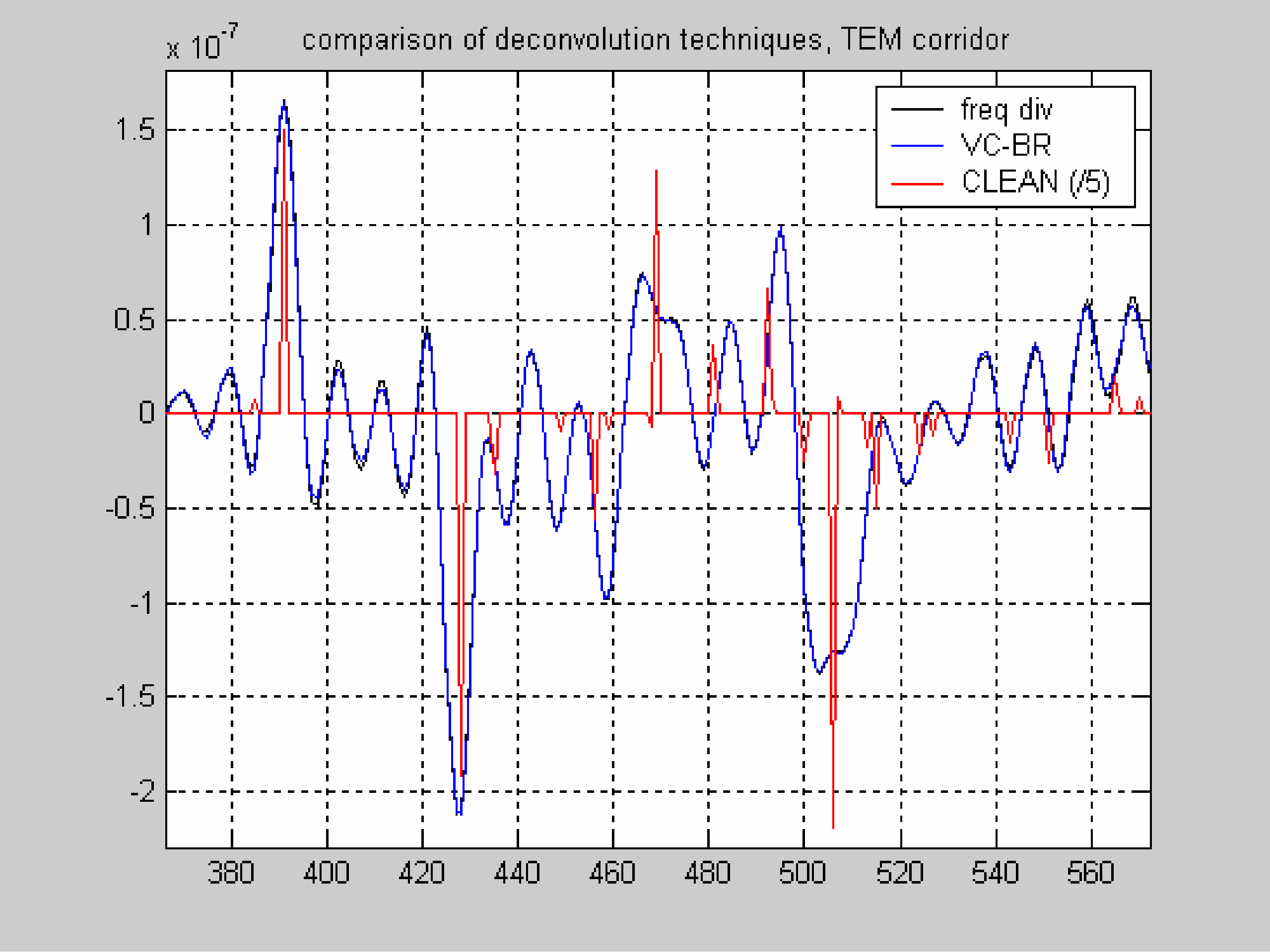
$$r(t) = \sum_k a_k p_{tx}(t - \tau_k)$$

- Will also examine frequency domain models

Finding the Channel Impulse Response

- Deconvolve $p_{tx}(t)$ from $r(t)$ to find $h(t)$
  - Frequency domain techniques examined
    - Inherently band-limits the calculated impulse response
    - Continuous impulse response must be binned
    - Limited resolution
  - CLEAN algorithm
    - Process in time domain
    - Matches a tapped delay line type model
    - Finer resolution

CLEAN vs. Frequency Domain Deconvolution



- Frequency domain results in band-limited IR
- Frequency domain requires binning of data to determine path locations

Channel Statistics

- Time Dispersion Statistics
  - No correlation w/ distance observable (more data possibly needed)
  - -15dB threshold

Time dispersion parameters

Averages (in ns)		Mean Excess Delay	RMS Delay Spread	Maximum Excess Delay
TEM horns	LOS	0.80	0.53	4.03
	NLOS	2.09	2.61	23.89
Bicones	LOS	3.93	4.74	35.60
	NLOS	10.75	10.27	63.55

Channel Statistics

Number of observed multipaths

(-15 dB threshold)		Number of Paths
TEM horns	LOS	7.0
	NLOS	19.3
Bicones	LOS	23.2
	NLOS	52.9

Significance of inverted paths

		% pulses inverted	% E in inverted pulses
TEM horns	LOS	46.3	32.3
	NLOS	41.2	32.3
Bicones	LOS	46.7	49.7
	NLOS	47.6	41.2

Log-Distance Path loss model based on receiver structures

- Energy captured depends on assumed receiver structure
- 3 structures have been investigated
  - Total energy detector (Integrates over a period of time to obtain all the energy) – Most commonly used
  - Threshold energy detector
  - Rake receiver (A threshold energy detector with multiple fingers)
- General path loss model

$$PL(d) = PL_0 + 10.\gamma \log_{10}\left(\frac{d}{d_0}\right) + X_\sigma$$

- Different receiver structures lead to different values of path loss exponent γ and standard deviation of X_σ

Log-Distance Path loss model – Results (Contd.)

	Bicone n	Bicone σ	TEM n	TEM σ	TOTAL n	TOTAL σ
LOS	1.66	1.7076	1.66	1.6150	1.66	1.6640
NLOS	2.5	3.1939	2.66	6.0316	2.58	4.8798
TOTAL	1.83	4.1873	1.87	5.6979	1.85	4.9809

Table 1. Summary of path loss exponent and std. deviation (Total path loss)

	Bicone n	Bicone σ	TEM n	TEM σ	TOTAL n	TOTAL σ
LOS	1.88	1.6133	1.87	1.2689	1.88	1.4631
NLOS	2.85	6.3794	2.91	9.0094	2.88	7.8106
TOTAL	2.08	5.5442	2.08	6.9039	2.08	6.2399

Table 2. Summary of path loss exponent and std. deviation (Peak detector)

- Path loss exponent and variance for peak energy is *higher* compared to total path loss results
- Can be reduced by deploying a Rake receiver

Current and Future Directions

- Additional indoor measurements
  - Time and frequency domain
- Outdoor measurement campaign on-going
  - Several frequency bands/bandwidths
- Modeling
  - Additional investigation tapped delay line model
  - Distributions for various parameters need to be fit to data
    - Energy decay
    - Amplitude distributions
    - # of paths vs τ_{rms}
    - Correlation between τ_{rms} and Distance
    - Other details
  - AR frequency domain modeling
  - Possibly per path frequency dependent modeling